Early Beam Injection in the Fermilab Booster & its Implementation Plan

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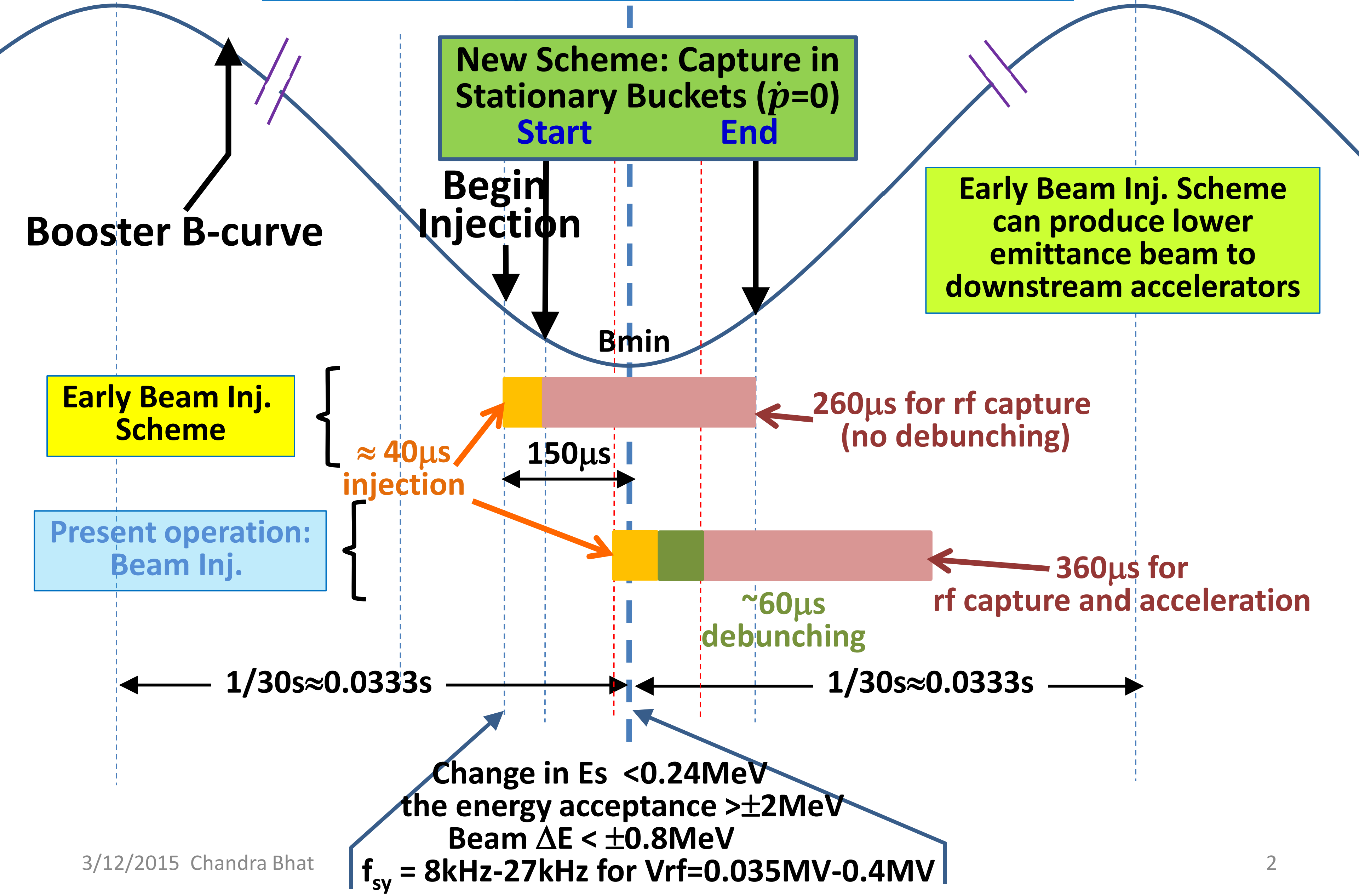
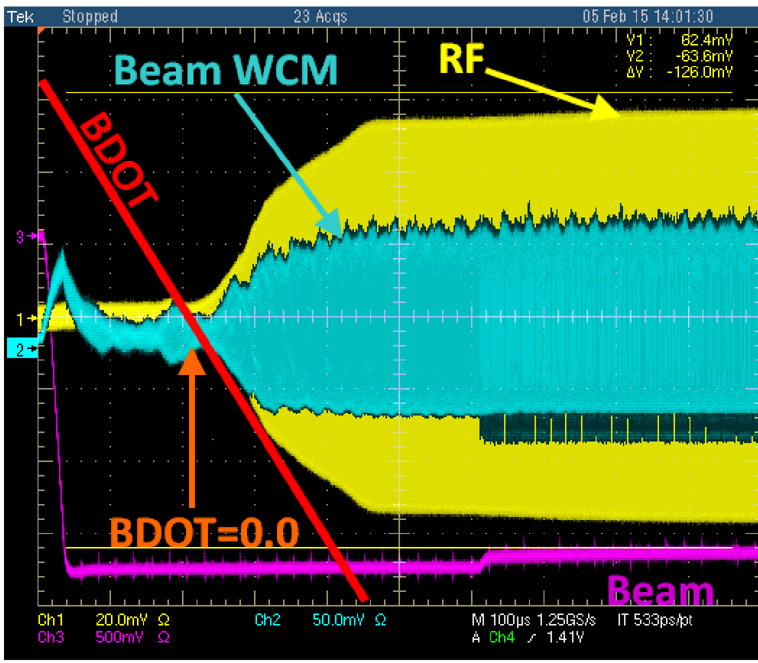
Abstract:
Over the past 6-8 months we have made significant progress in understanding the Early Injection Scheme (EIS) via simulations as well as by the experiments in the Booster. The studies needs dedicated beam time, hence, we developed 1-shot sequence which will help us to make progress in the beam studies even during the nominal beam operation. The results from the simulations on the EIS shows that one can operate Booster at a lower rf power, produce lower emittance beam and no beam losses under current operational scenario. The conclusions from a preliminary analysis (presented here) of the beam data from EIS are, 1) one can lower the rf power by ~15%, 2) beam delivery efficiency is about 90%, comparable to that with the current operation, even with a part of the scheme implemented in the tests. We present game plan for implementation of the full scheme in operation.

Schematic of the Beam Capture in the Booster

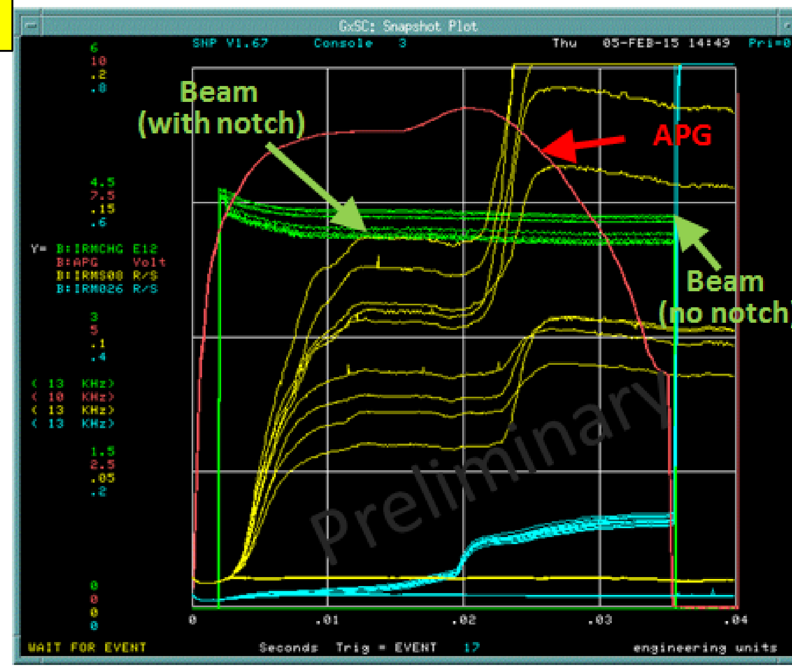


Beam Studies on Early Injection Scheme

- The Beam studies were made on \$17
- Following Changes were made:
  - beam injection at 144 μs earlier than BDOT=0.0
    - ⇒ B:RSTDLY changed to 64491μs from nominal value of 64635 μs
  - New RF, ROF and Paraphase curves, B:VFINJ
  - Additional tuning was needed at transition crossing (some times)

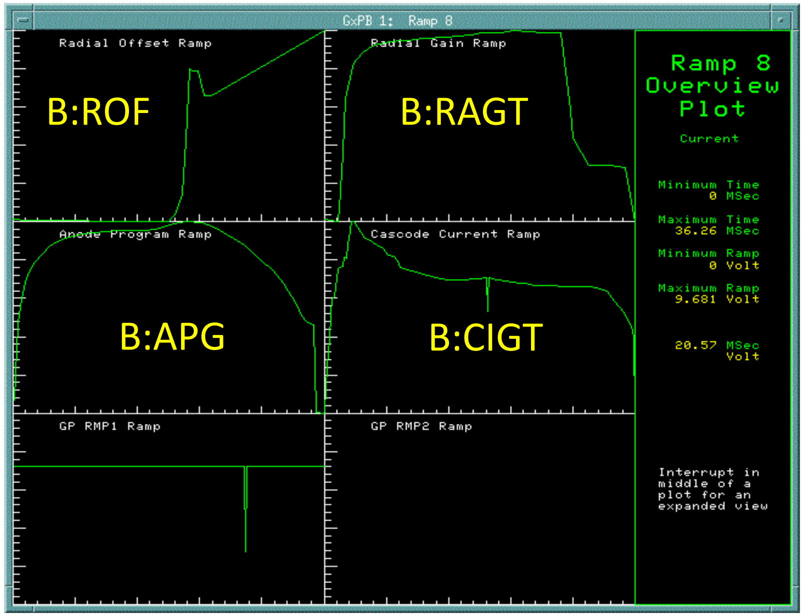


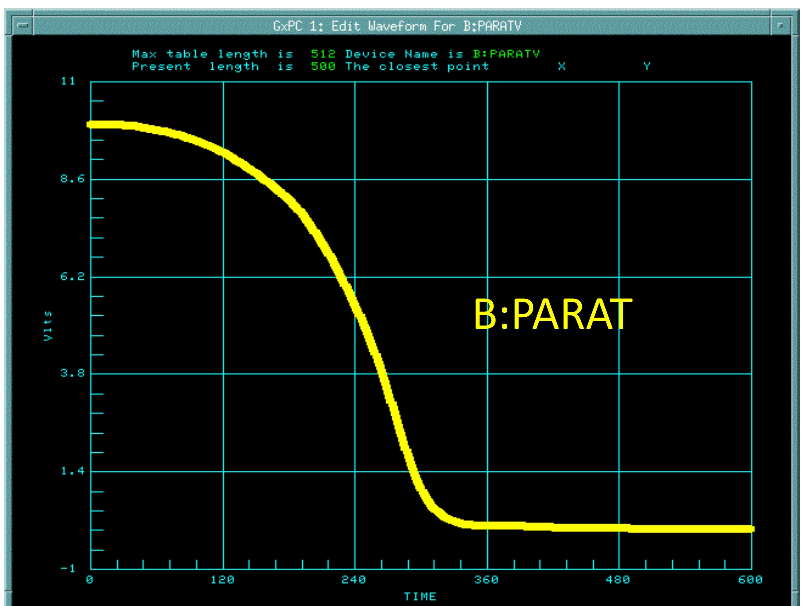
13BT

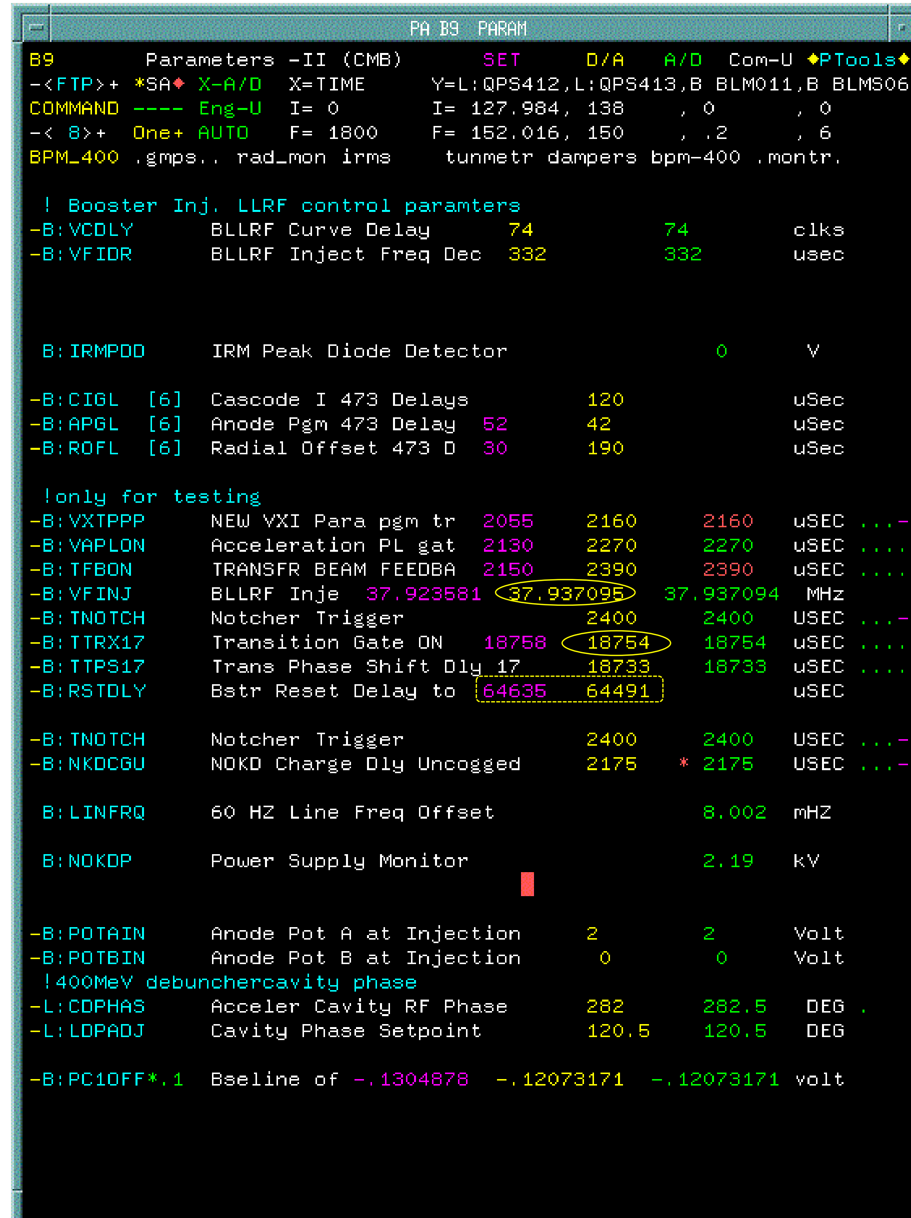


The beam lifetime was good for > First 1 ms!

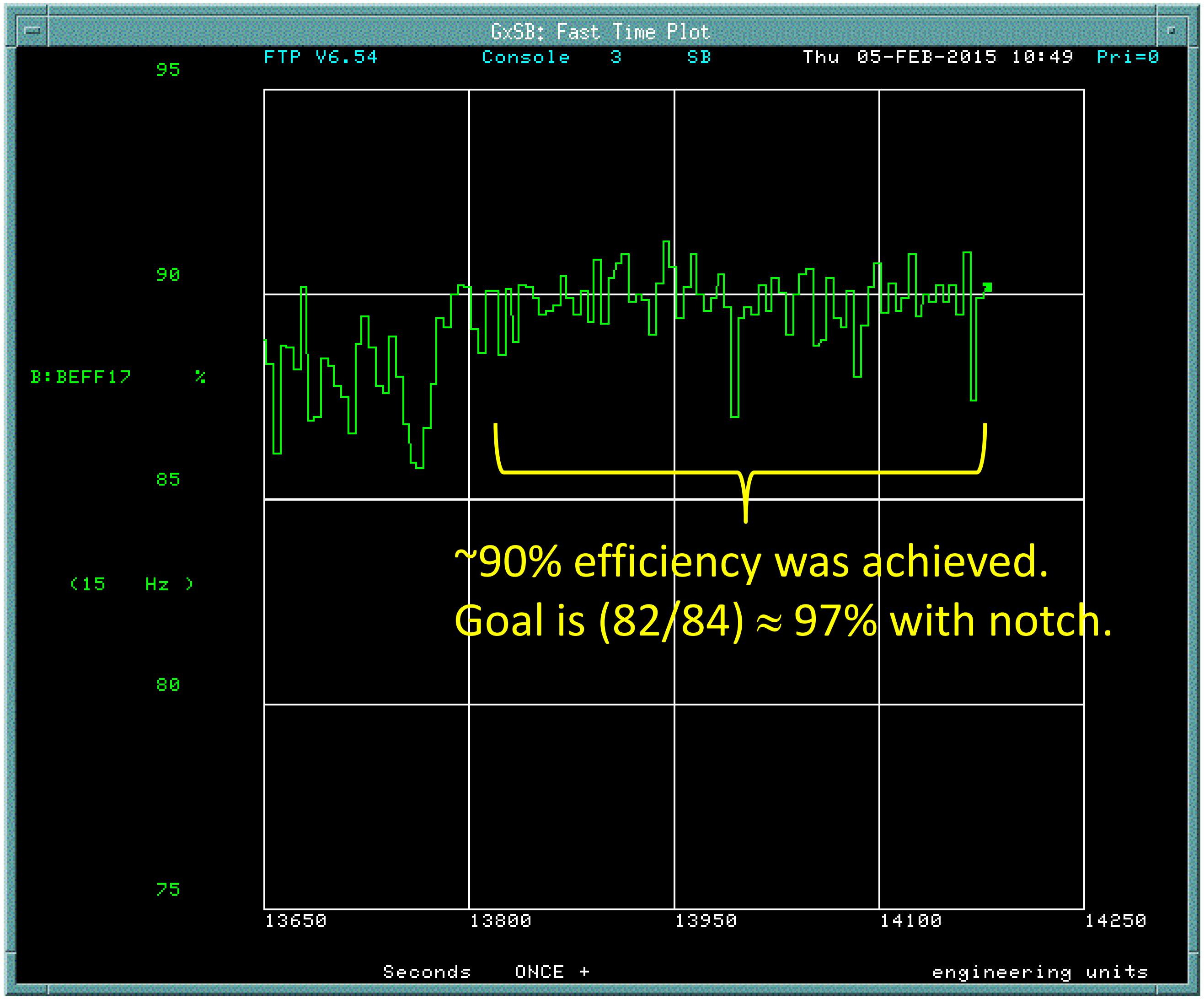
New Settings for a few Parameters





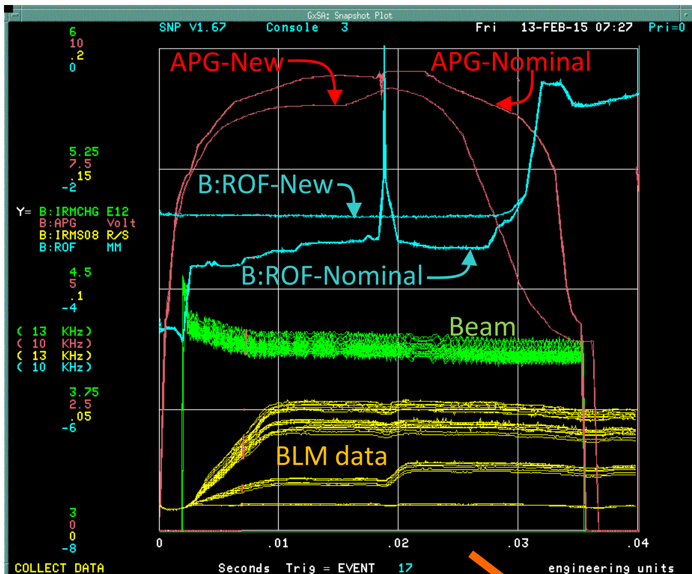


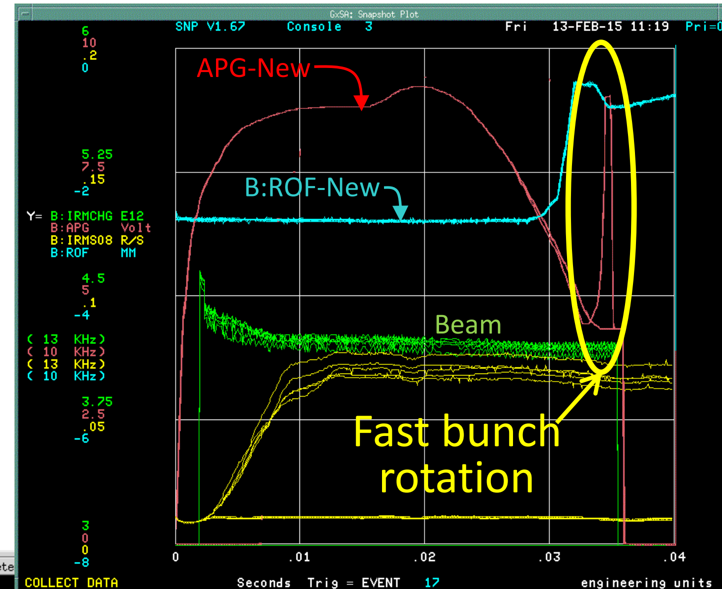
Beam Efficiency on $17 with 13BT

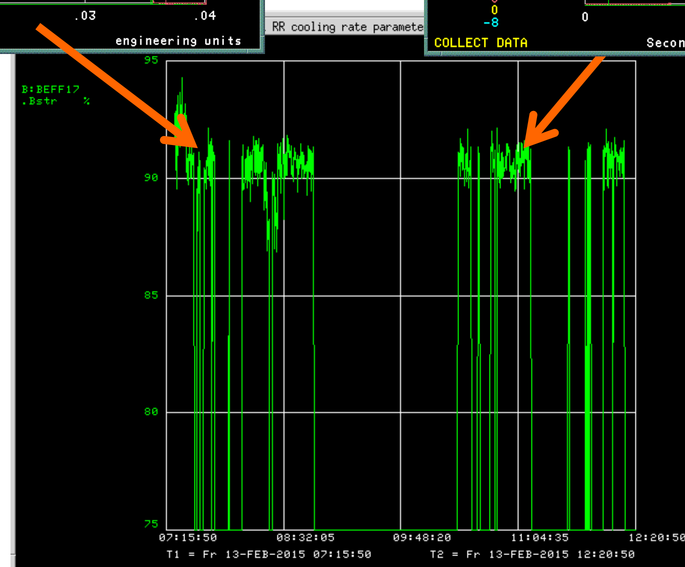


Studies Continued with B:RSTDLY=64635 (standard Val.)

- Did continue our beam studies to optimize the APG and ROF curves on $17, B29 (Ramp 8) to smooth and reduce the RF power.





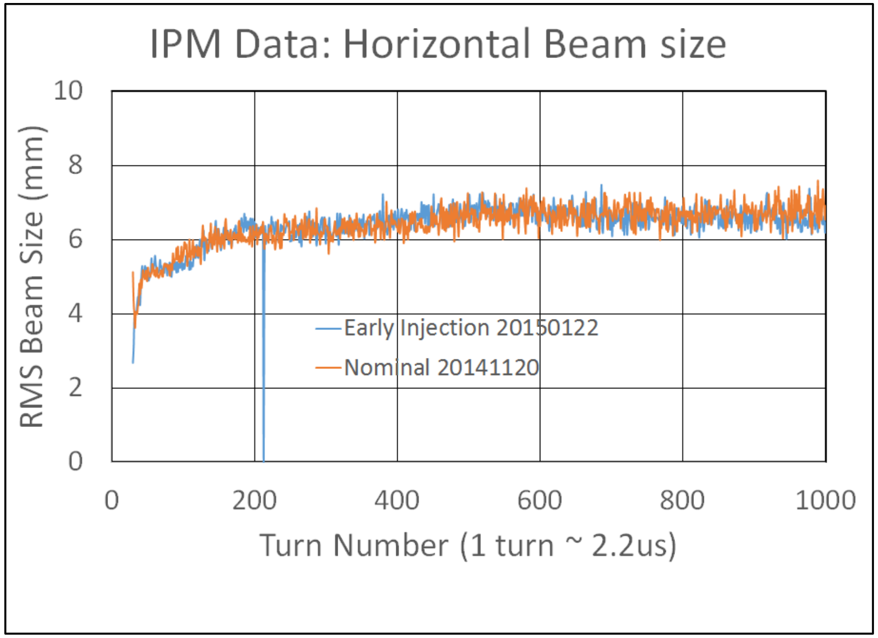


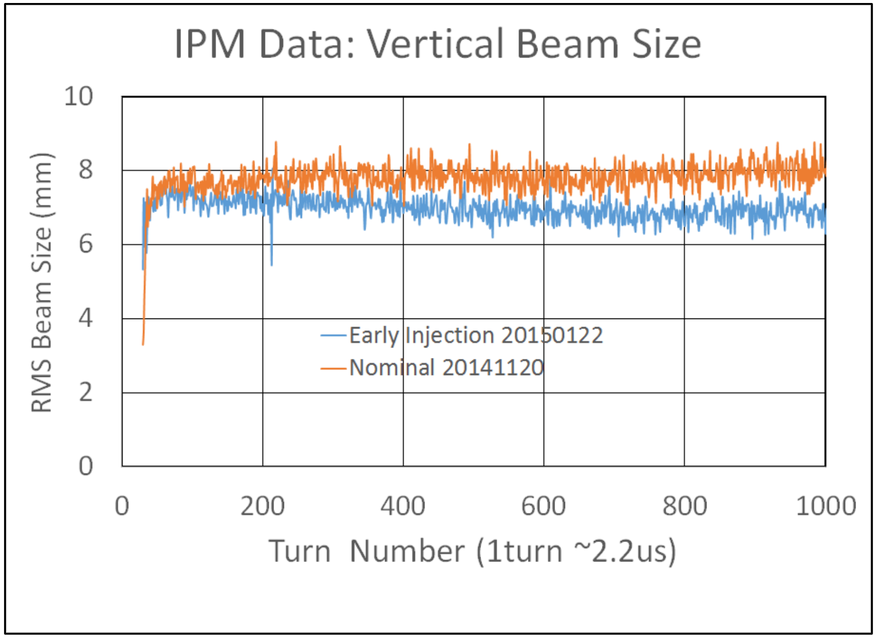
The difference between new and nominal APG (Vrf) curves on the cycle are shown for comparison.

>90% beam efficiency with 13BT.

Samples of Transverse Beam Sizes for the First 2 ms

Data are for 14BT beam





Game plan & Issue

- Early Injection Scheme can be made operational immediately
  - Set the B:RSTDLY = 64491 μs
  - Set new values for B:VFINJ, B:TTRXnn (turn dependent), … parameters indicated in earlier. This enables us to start beam capture immediately after Bmin.
  - Our immediate goal is to provide the beam with efficiency >85% (so far we have proved efficiency ~90% with 13BT).
    ← We may have to inform the users about this new development and why we are doing this.

  ← No showstopper
- We will continue to optimize various parameters for better efficiency (similar to what is currently being done). This tuning is transparent to down-stream machines. Also improve on
  - PARAT, **APG**, ROF … curves, tune, chromaticity curves etc.,

This gives us an ability to make progress; reaching 97% efficiency with notch in place .

Game plan & Issue (cont.)

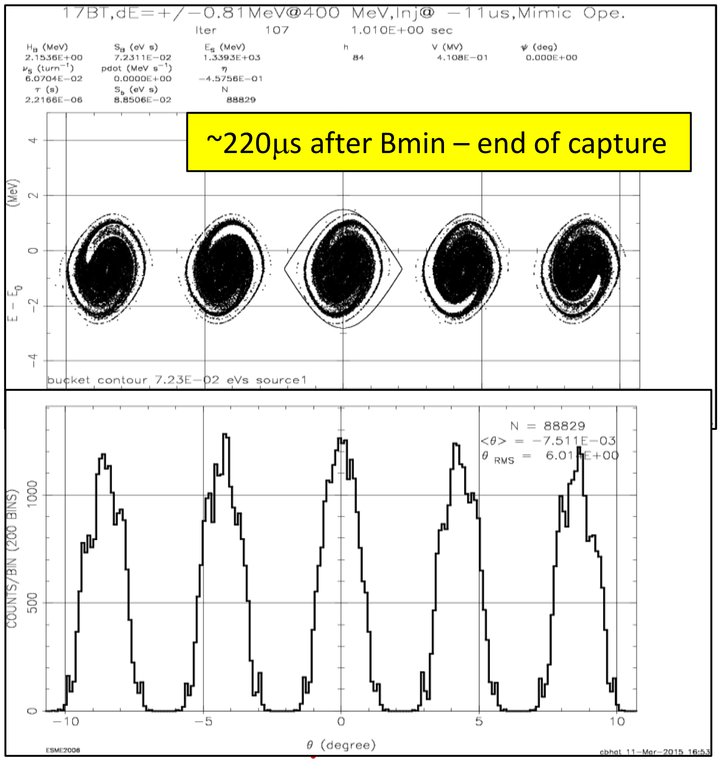
- So far, we have taken only the partial benefits of Early Injection Scheme, i.e.,
  - Start beam rf capture immediately after Bmin though beam injection is about 144 μs earlier (in contrast, operationally we wait for 100s of μs on the up-ramp before rf paraphrase is turned on).
- To take full benefit we need
  - To move the beam capture soon after the completion of the beam injection, i.e., B:VCDLY and B:VFIDR need to be referenced to TCLK
  - Currently, we use a calculated frequency curve which does not match with the value at injection (therefore we adjust B:VFINJ). We need better frequency synchronization bet. LLRF and real freq..
  - We also work on fast bunch rotation at extraction which is more clean and gives better lower energy spread beam to slip-stacking in RR.
  - If LINAC can give us more number of turns we can accommodate them!

Backup slides

Simulation of Beam Capture at Injection

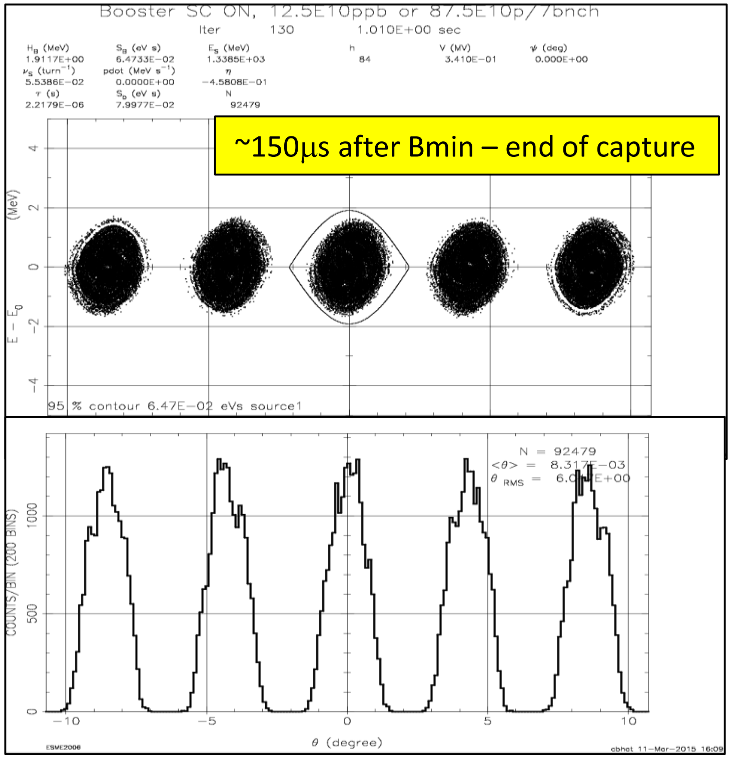
Used dE_{full} @ Inj= ±0.8 MeV (Measured at Inj.)

Operational Scheme:
Beam inj. at -11 μs w.r.t. Bmin (17BT)



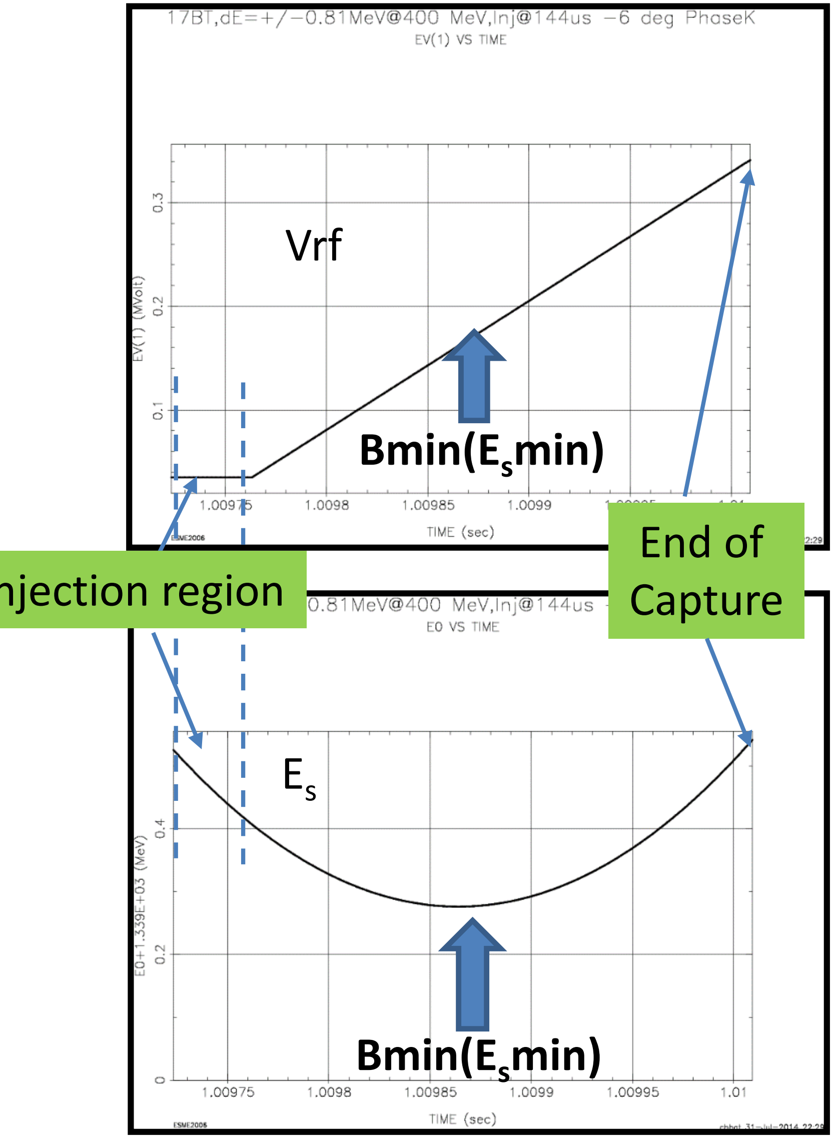
Bucket Area = 0.07 eVs
ε_L = 0.06 eVs
~2% Beam loss even without SC effects

Early Injection Scheme:
Beam Inj. at -144μs w.r.t. Bmin (17BT)



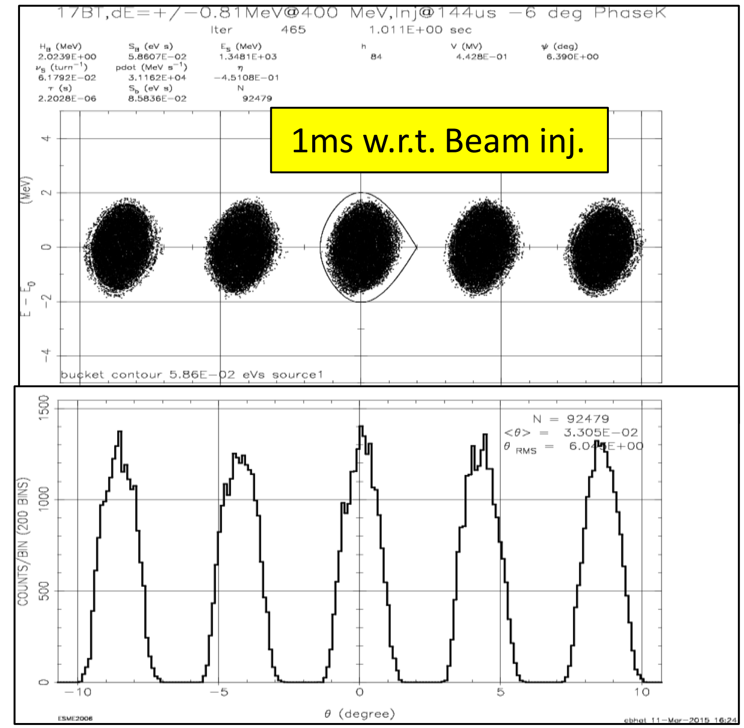
Bucket Area=0.065 eVs
ε_L = 0.045 eVs
No Beam loss

Early Inj. Scheme: Beam at ~1ms w.r.t. Inj.



Beam Inj. at -144μs w.r.t. Bmin (16BT)

Simulations with longitudinal SC(symmetric)



Vrf (@400 μs) = 0.44 MV

Bucket Area=0.06 eVs

$\varepsilon_L \approx \pi \times 0.008\mu sc \times 1.8$ MeV = 0.045 eVs

No Beam loss even with SC effect

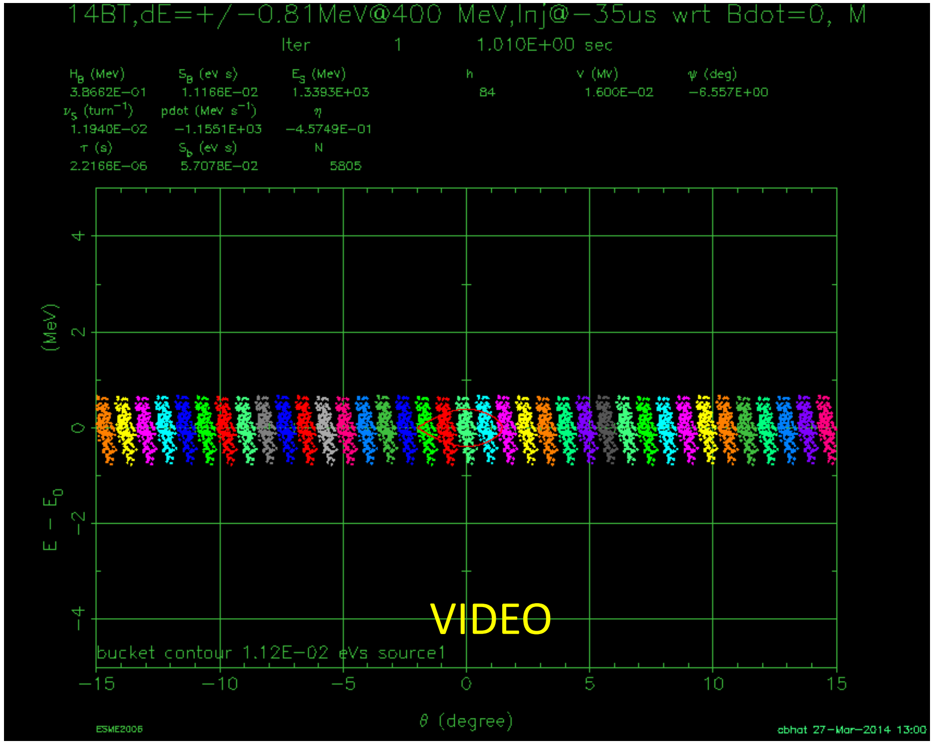
~30% lower rf power on average over the cycle

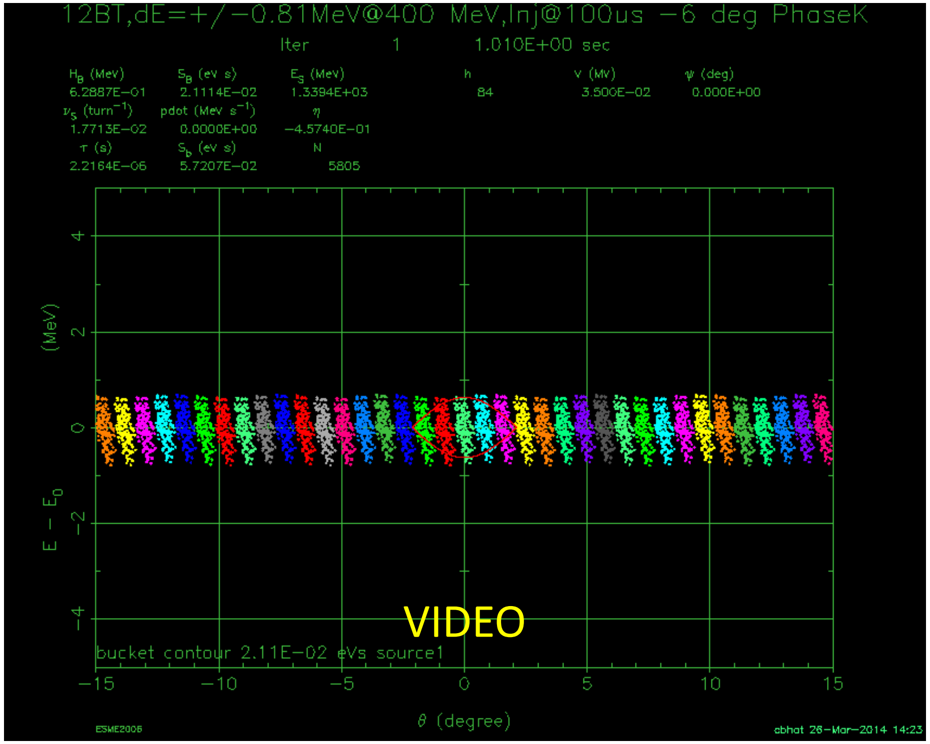
Simulation for Injection → Extraction in the Booster

Proposed Scheme: **Inj@Bdot=0 at -100μs,** Capture from -64 μs to 135μs, with a phase kick of ~ 6 deg after transition crossing.

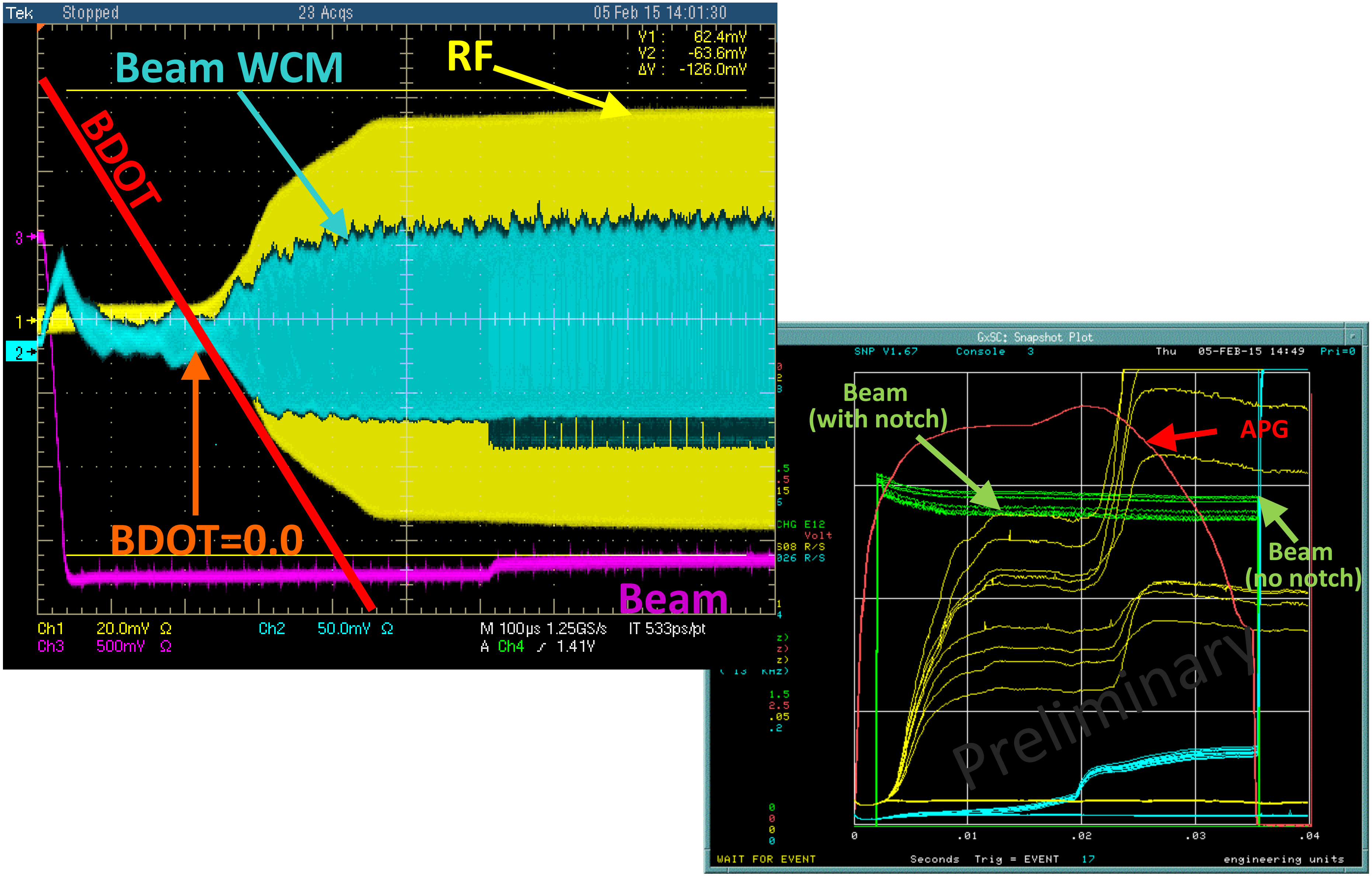
This video is for Inj → Extraction

Mimic of Operational Scheme





Recent Beam Studies on Early Injection

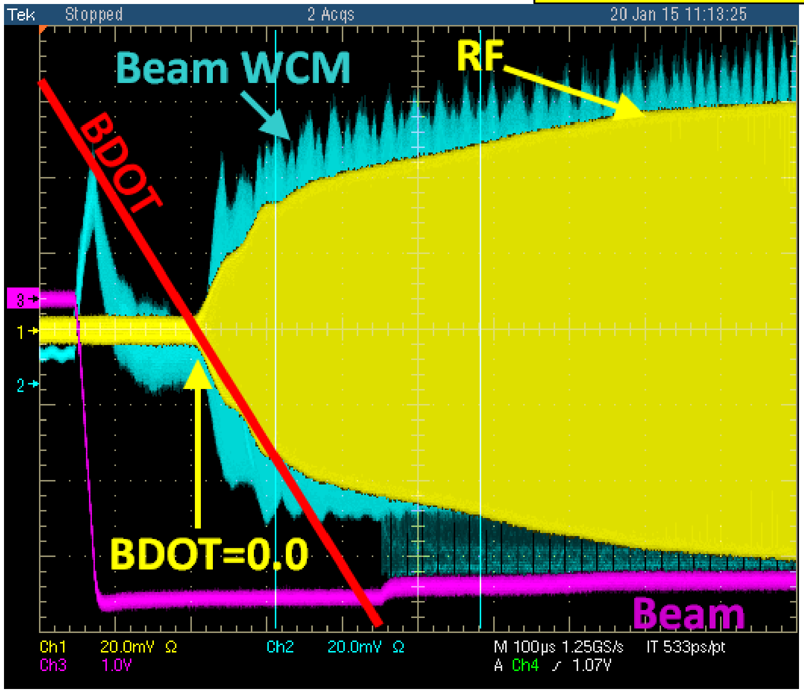


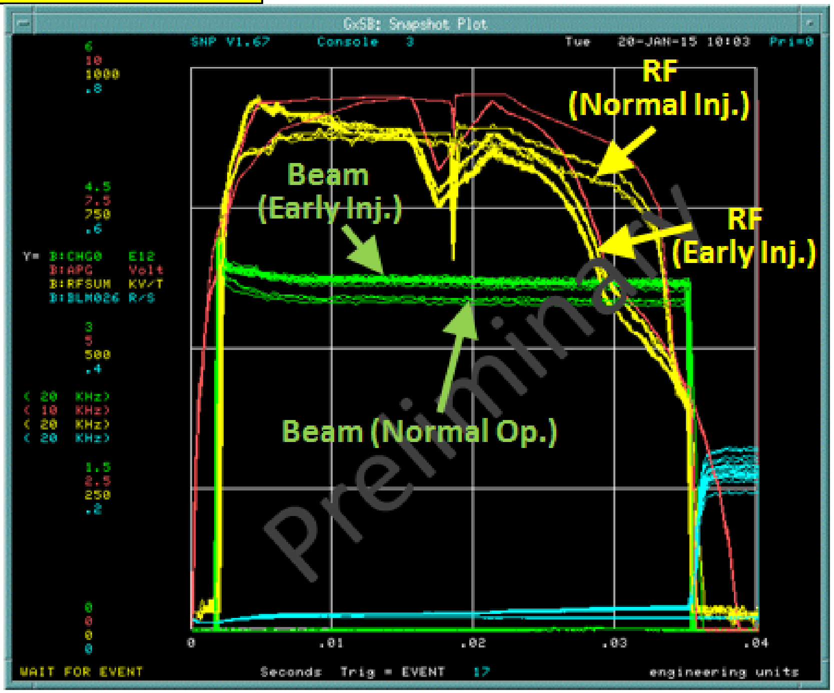
Beam Studies on Early Injection Scheme

Conditions:

1) beam injection at 144 μs earlier than BDOT=0.0
2) New RF, ROF and Paraphase curves
3) Additional tuning was done at transition crossing

12 BT after transition tuning





Flans:

We would like to start beam capture as early as possible after the beam injection with proper frequency curve. This needs some changes to the timing and hardwares. This work is in progress.